DISCUSSION ON "RADIO NOISE"

AT THE CONVENTION ON SCIENTIFIC RADIO, 8TH APRIL, 1948

Dr. R. A. Smith: Referring to Dr. MacDonald's paper, it is not clear why the study of the very-low-frequency components of noise should be related in any way to the study of the very-high-frequency noise with which one was concerned in radar receivers. The crystal in which incoming signals are mixed with those from the local oscillator is generally biased by having direct current passed through it. This direct current, in passing through the crystal, is itself subject to very-low-frequency fluctuations, which themselves may appear as modulation on the intermediate frequency. Very-low-frequency fluctuations can therefore not be ignored, even when considering the extremely-high-frequency end of the spectrum. It is rather significant that in the last few years attention has been more and more focused on the low-frequency end of the noise spectrum.

If the frequency spectrum of fluctuation noise is examined theoretically, it is easy to show that, as the frequency tends to zero, the rate of increase of noise energy per unit bandwidth should also tend to zero, no matter what is the form of the random events causing the fluctuation. Experiments on various common forms of low-frequency noise, however, show that the noise energy per unit bandwidth is still increasing rapidly, even at a frequency of $\frac{1}{4}$ c/s. This applies to "flicker" noise in valves, current noise in resistors, etc. So far as I am aware, no one has yet reached a frequency sufficiently low to indicate that the noise is no longer increasing as the frequency is decreased. This is a field which I commend to experimental researchers for investigation.

Regarding noise fluctuation from a photo-electric cell, the author states that a rather significant experimental fact is the absence of this effect (low-frequency noise in addition to "shot effect" noise). Many engineers appear to think that it is obvious that there should not be any abnormal low-frequency noise in photo-electric cells, because they take it for granted that each light quantum ejects an electron and that the quanta arrive in a purely random fashion. The author has pointed out that each quantum has in fact only a relatively small probability of ejecting an electron. In the best photo-electric cells the probability is only 1 in 5, and if that probability can fluctuate at low frequency, then one should expect to find increased low-frequency components of noise modulation, even in a photo-electric cell. It is not at all obvious that there should be none. We have, however, carried out some careful experiments and found no low-frequency fluctuations in photo-electric cells in excess of those attributable to shot effect.

It has been known for a long time that there was a source of noise associated with magnetic materials, a phenomenon known as the Barkhausen effect. When a piece of magnetic material is taken from saturation in one direction to saturation in another, it does not swing over smoothly, but in a series of jerks. For very-low-frequency amplifiers, and particularly d.c. amplifiers, magnetic materials are now being used to convert the input signals to a relatively high frequency before amplification. It is found that the limit of sensitivity of these amplifiers is set, not by Johnston noise, but by Barkhausen noise. Because of this limit it has not been possible to develop such amplifiers to have such a high sensitivity as can be obtained with an a.c. amplifier of conventional design.

I should like to mention the extreme sensitivity which modern technique in the design of amplifiers has achieved. A low-frequency amplifier has been developed at T.R.E. for use at frequencies of the order of 5 c/s, with which the Johnson noise in a 1-c/s bandwidth generated by a 1-ohm resistor connected across the input is just visible above the internal noise generated by the amplifier when the output is connected to a recorder meter.

Mr. D. A. Bell: The "awkward and long standing problem of the interrelation between shot noise and thermal noise in thermionic valves," mentioned by Dr. MacDonald, can be solved as soon as the mechanism is considered. Our shot-noise theory started off on the right lines, because the formula for temperature-limited diodes was deduced from the movements of individual electrons, and by summing them we obtained the mean current plus the fluctuation. Then, I think, the Nyquist theorem for thermal noise led us off on the wrong track by using thermodynamics quite regardless of the question of internal mechanism. But, between 1936 and 1938, a number of scientists demonstrated that the Nyquist formula for a metallic resistor could be deduced from the behaviour of the conduction electrons, which was a return from thermodynamics to mechanism. From there the remaining step is to go back to the valve, now in a space-charge-limited condition, and similarly to deduce the reduction factor for the smoothed shot noise.

In fact, the various ideas of noise in a space-charge-limited valve all reduce to two hypotheses. According to one, the whole thermal component of electron velocity during its transit from the cathode to the anode is effective. According to the other, only the difference between the total thermal velocity and the mean velocity is effective, and the difference between those two is a factor $(1 - \pi/4)$. As the ratio is about 4 : 1, it seems easy to determine experimentally which hypothesis is correct, but, so far as I can ascertain, no one has succeeded in doing so. Experimenters who have set out to use diodes found that the electrons bounced back from the anode and spoiled the results, and those who measured triodes had to make so many allowances

for the effect of non-uniform field that the results were not convincing. Once we have settled experimentally the issue between these two hypotheses, I think we shall know completely the interrelation between thermal noise in a resistor and the shot noise in a valve.

Dr. H. G. Booker: I should like to refer to radio noise from thunderstorms, and particularly to the interpretation of observations of the phenomenon made in tropical regions. Dr. Thomas has drawn attention to the different types of seasonal variation experienced at different locations in the tropics, the contrast between results for Calcutta and Colombo being a striking example. I feel certain that many of these anomalies can be rationalized by analysing the results in relation to what meteorologists call the equatorial front. This front is a zone where air-masses originating in the northern and southern hemispheres meet. It forms round the earth a girdle that may be thought of as the meteorological equator, although its actual position at any time differs considerably from that of the geographical equator, so much so that many meteorologists prefer to call it the intertropical front. On any particular day this front may be located by ordinary synoptic meteorological data and represented as a wavy line round the earth. The exact position varies from day to day, and its general location moves seasonally north and south with the sun, the amount of the movement depending on the distribution of land and sea. Movement of the equatorial front across a particular location is associated with the onset of a monsoon season. The degree of activity along the front varies a good deal from time to time and from place to place, being generally much greater over land than over sea. The equatorial front, particularly where it crosses land-masses, is undoubtedly associated with a good deal of radio noise, and it is instructive to see how far the seasonal variation of noise at tropical locations can be explained by reference to the current position of the front.

In Colombo, the equatorial front moves northward across Ceylon in April, and southward again in October. The peaks of noise around April and October shown by Dr. Thomas are therefore very suggestive. The equatorial front in its northward movement reaches Calcutta in early June. It remains in the vicinity of Northern India until about the end of September and then recedes southward again. High noise-level might therefore be expected at Calcutta from June to September. This tendency is reasonably apparent in one of Dr. Thomas's illustrations, except that April and May are also months of high noise-level. But it is quite well known that in Bengal and Burma weather phenomena not very dissimilar from those which occur during the south-west monsoon are also experienced in April and May before the actual arrival of the equatorial front. Indeed, these pre-monsoon phenomena are sometimes called "the little monsoon." It seems reasonably obvious that the high noise-level at Calcutta in April and May is associated with the little monsoon, while that occurring from June to September is associated with the south-west monsoon proper.

I feel certain that, by proceeding along these lines, most of the obvious features of radio noise experienced in the tropics could be explained in terms of well-known meteorological phenomena, in many cases associated with the equatorial front. It would be interesting to see, for each of the tropical and sub-tropical stations for which data are available, a plot of mean daily noise-level against distance from the equatorial front, measured in some suitable manner. There might well be a way of doing this that would lead to roughly similar results for many tropical locations, and this would go far to rationalizing the observations of radio noise in the tropics.

Mr. R. V. Whelpton: Dr. Thomas has presented a great deal of information about radio noise on frequencies between 2·5 and 20 Mc/s, and this is undoubtedly of great value to radiocommunications. There is, however, an international agreement to develop radio aids to long-range navigation in the 90–110-kc/s frequency band. With present available information on radio noise and propagation characteristics at these low frequencies, the radio engineer cannot predict with any accuracy the signal/noise ratios at long distances from a given transmitting station, and therefore cannot design properly a long-range radio-navigation system.

If there is an international requirement for such a system, there must be international co-operation on research into radio propagation and noise on low frequencies.

It is interesting that Dr. Wormell's records shows some rapid and irregular fluctuations with a frequency of the order of 10–20 kc/s. It would be valuable to know if similar "atmospherics" occur in the region of 100 kc/s. In fact, a thorough investigation of the amplitude and waveform of "noise" below 300 kc/s is required.

Mr. W. Ross: Dr. Thomas states that predictions of noise based on the assumption that the noise arises from thunderstorm areas, and on calculations which involve oblique-incidence-propagation theory, do not fit the facts. However, bearing in mind Dr. Beynon's* remarks on the difficulties of reconciling measurements of ionospheric absorption at vertical incidence with signal strength received over oblique-incidence paths, it does not seem surprising that there should not be close agreement.

In one of the figures presented by the author, the noise level at Delhi was shown as being remarkably small and constant, suggesting an unsatisfactory observation at that station.

Mr. G. Millington: I should like to know Dr. Thomas's view with regard to the figure of 0·3 μV/m, given in Appendix 2 of the Final Acts of the I.T.U. Atlantic City Conference for the maximum permissible level of unwanted signal interfering with a wanted signal on the same frequency. This figure is closely related to the level of radio noise, as it is assumed that the level of the wanted signal is only that required to give an acceptable service in the presence of radio noise.

The work described by Messrs. Hey and Ryle has all been done on high frequencies. In a recent letter to *Nature*, Dr. Menzel suggested that the sun may be emitting noise of extremely low frequency (perhaps 1–2 c/s). If this is so, then, as he points out, we may have an explanation of night-time ionization, as such waves would be diffracted right round the earth with very little attenuation. I should like to know the opinion of the authors as to the likelihood of such long waves being included in the spectrum of the sun's radiation.

Mr. W. A. Johnson: Dr. Thomas referred to the possibility of strong local sources of noise, which I should prefer to call meteorological noise. A good deal of data has now been accumulated regarding this type of noise in aircraft, and it seems to amount to about 37% of the total noise experienced in aircraft radio from external sources. Very little observation has been made on the corresponding noise from vegetation, mountain peaks, etc., which can discharge in the vicinity—say within 15–20 km—of the receiving station. I should welcome further information on this aspect.

Dr. H. G. Hopkins: There is a significant difference in approach between the paper by Dr. Wormell and Mr. Pierce and that by Dr. Thomas. In the first, the atmospheric is considered as an individual entity, in the other the collective effect of many atmospherics is studied. British practical experience over the past few years in the routine location, for meteorological purposes, of thunderstorms at long ranges by radio direction-finding has shown that the first method is particularly fruitful. When considering the effects of atmospherics on radiocommunication

* See page 325.

and navigation systems, however, it is natural to develop the statistical approach. In using atmospherics as a means of examining propagation phenomena, it appears that both avenues of study are worth following.

Mr. Caradoc Williams: I should like to try to relate some of Dr. Thomas's remarks to some experiences of mine during recent propagational investigations at the Azores and in Iceland. We were concerned with the behaviour of radio waves in the region of 100 kc/s, and at both places we set up receiving stations for a short period from which we were able to get an estimate of the signal strength of transmissions from this country and of the noise prevailing at the time. The important point which I wish to bring out is this. In plotting the characteristics of the signal strength and the noise in both the Azores and in the northern latitude of Iceland, it was noticeable that the signal variations followed the diurnal characteristic. The noise variations followed the signal strength characteristic at the Azores fairly closely; in fact, it was observed that the noise level rose at the same time as the signal strength was rising after the period of sunset, and dropped during the period of sunrise. This immediately suggested that the noise which was being received came from a distant source, reflected by the ionosphere.

In Iceland no such correlation between the signal strength and noise appeared to be present. The signal strength followed the expected diurnal fluctuation, but the noise level was practically constant throughout the whole of the day and night. The conclusion to which I came was that the noise level in the northern latitude during the period in which we made the investigation was very low, and that it was low for possibly 1 000 miles or more around the point where observations were taking place, because, if noise had been present in this area, it would in all probability have been observed at the receiver by reflection from the ionosphere.

Dr. R. L. Smith-Rose: It has been suggested that at present we do not really know much about atmospherics. It should be remembered, however, that Sir Robert Watson-Watt spent twenty years studying atmospherics and leading an active team in that study, and that much of that work was done on long waves.

The history of research on atmospherics in this country is interesting. About twelve years ago a committee of the Radio Research Board, which was controlling this work, began to doubt whether it was worth while going on with the investigations; this doubt came from two quarters. In the first instance, the practical engineer, who was responsible for radiocommunication, thought that he had reached the point at which his work was no longer being restricted by atmospheric disturbances. He had apparently attained such a position in maintaining frequency stability of transmitters and had achieved such high selectivity in receivers that the difficulties he had had in the past of getting a signal which was adequate in relation to the local noise-field no longer existed. Secondly, meteorologists said that they were not very interested in the study of atmospherics, and that, if it were not very useful to the radio engineer, it was about time that this study was suspended; and, as far as I remember, in 1937 the research work did stop.

At the outbreak of war, the meteorologists asked to be supplied with radio direction-finders for determining the position of storms giving rise to atmospherics; and during the war, with the aid of the direction finders which he had in his own hands, the meteorologist became convinced that the instrument was essential for him in weather forecasting. An improved type of the same instrument is in daily use by meteorologists. Also during the war, the communication engineers, while they know something about the phenomena of the ionosphere which affect the strength of signals, were limited by the lack of precise knowledge about atmospheric noise. We therefore started investigations on the lines which have been described by Dr. Thomas, because there had, in fact, hitherto been very little data on noise at high frequencies.

Now the radio engineer complains that we do not know anything about atmospheric disturbances on long waves, and we are thus being pressed to resume an investigation which was interrupted over ten years ago.

The moral of this experience seems to be that it is not always good for the practical radio engineer to tell the research worker to discontinue some of his investigations.

Dr. J. L. Pawsey: The observations which Mr. Hey described in 1942* gave the first definite evidence of which I am aware of high-intensity solar radiation on radio frequencies. The science to which that observation gave birth has now given astronomy a new tool and may give important results in the field of the generation of electromagnetic waves in ionized gases.

I should like to refer to the second fundamental discovery made by Mr. Hey and his colleagues,† namely the short-period variations in cosmic noise originating in an area less than 2 deg in diameter in the constellation of Cygnus. Further observations of this source have been made by Bolton and Stanley‡ of the Australian Council for Scientific and Industrial Research. They used a technique depending on interference between a direct ray and one reflected from the sea as the source rose and set. This gives rise to a series of maxima and minima of the received radiation. The location and the size of the source may be derived from the timing of the minima and the ratio of maxima to minima respectively.

From such observations, Bolton and Stanley concluded that: The source is less than 8 min of arc in diameter (an observational limit), and may well be a point source; the radiation from this source has a steady component, which could not be recognized as originating in a very small region by Mr. Hey, together with the variable one recognized by him; the position of the source is R.A.: 19 hr 58 min 47 sec $\pm$ 10 sec, Declination: $+ 41° 47' \pm 7'$ (1947 co-ordinates). No motion of the source has been detected over several months of observations.

The position of the source which, from the absence of apparent movement, is apparently at stellar distances, does not coincide with any outstanding stellar object. It falls on an ordinary part of the Milky Way. The observed flux density is surprisingly high; it is of the same order at 100 Mc/s as that from the sun at quiet periods, despite a presumed vastly greater distance. It is also of the same order as that from the whole of the subsidiary maximum of cosmic noise observed in Cygnus when galactic noise contours are plotted over the whole sky.

These facts, together with that of rapid variation, scarcely fit the hypothesis of an origin in thermal radiation from vast clouds of interstellar gas. There must exist localized regions emitting vast amounts of radio-frequency energy. Perhaps they may prove to be new types of astronomical bodies.

The Cygnus source is not unique. It is only the most studied of the discrete sources of cosmic noise.

Mr. Ryle's use of interference between spaced aerials for discrimination against cosmic noise, for source-diameter measurements and for polarization measurements, represents an economy in equipment quite in the Cavendish Laboratory tradition. The results which he described have been largely duplicated in Australia, utilizing somewhat different methods, and I am happy to be able to say we agree on the main conclusions.

We have been interested in the possibility of the ionosphere

* HEY, J. S.: "Solar Radiations in the 4–6 metre Radio Wave-length Band," *Nature*, 1946, 157, p. 47.

† HEY, J. S., PARSONS, S. J. and PHILLIPS, J. W.: "Fluctuations in Cosmic Radiation at Radio Frequencies," *ibid.*, 1946, 158, p. 234.

‡ BOLTON, J. G. and STANLEY, G. J.: "Variable Source of Radio Frequency Radiation in the Constellation of Cygnus," *ibid.*, 1948, 161, p. 512.

influencing the waves. There is a double problem in that the lower atmosphere bends the waves in a complex manner, which is large for low angles of elevation, and ionospheric effects, if any, are superimposed on this.

We have used a method of allowing for refraction which neglects the ionosphere. At 200 Mc/s, we have obtained consistent results at angles of elevation above about 2°. At 60 Mc/s, the same technique has given apparent locations which move about over the face of the sun in an irregular manner. This may be due to irregular bending in the ionosphere which is significant at 60 but not at 200 Mc/s.

I have no opinion as to the validity of Dr. Menzel's ideas on low-frequency radiation, and I am waiting for the experimental evidence.

Dr. W. J. G. Beynon: Concerning Dr. Pawsey's noise measurements at sunrise on 100 Mc/s, I should like to ask whether refraction in the ionosphere may not influence the incoming radiation, possibly giving rise to some form of interference pattern in the received signals. For radiations from a sender located on the surface of the earth, the maximum possible angle of incidence at region F_2 is about 75°, whereas for the extra-terrestrial sources of radio waves completely-grazing incidence is possible. In such circumstances appreciable bending of noise radiations in the ionosphere might be expected, even at extremely high frequencies.

Mr. C. W. Earp: The authors refer to receiver noise in such a manner that one might take this to represent a fundamental basis or standard of comparison for measurement of galactic noise, and I should like to correct the possible impression that fundamental receiver noise exists at all. Practical receiver noise is usually made up, very largely, of shot noise in the anode of the first valve and of noise due to thermal agitation of the first grid circuit. The effect of the former may be reduced progressively by development of better valves. Furthermore, if the first grid circuit of a receiver is comprised of an aerial only—not terminated by a physical circuit—and if this aerial is perfect in the sense that its impedance is determined only by its radiation resistance, then the only source of noise is the space into which the aerial is pointing, and the amount of noise depends upon the effective temperature of that space. Thus, a receiver noise factor of 0 db does not by any means represent theoretical perfection.

The peaks of noise in inter-stellar space have been referred to, and I wonder how far we shall progress in time in being able to measure the troughs of noise. We should certainly not be satisfied with a receiver noise-factor of 0 db, and I look forward to the day when minus 40 db may be achieved.

Sir Edward Appleton: The present tense kept creeping into the remarks made by previous speakers in the discussion concerning stars in the Milky Way. I think we should remember that the radiation which forms the basis of these fascinating experiments actually left the Milky Way 20 000–30 000 years ago. Our evidence therefore relates to the conditions in the Milky Way during the Ice Age in this country.

I should like to stress how beautifully this work on solar and cosmic radio noise has developed on the experimental side. But there has not been by any means the same amount of progress in the theoretical elucidation. How do we account for these enormous effective temperatures associated with sunspots? These high effective temperatures mean that somewhere or other in the solar atmosphere there are electrons with velocities corresponding to energy of a million volts. Dr. Martyn has dealt with the subject of the quiet sun and the corona in a satisfactory fashion, but I have not yet seen a satisfactory theory of the noise which originates in sunspot regions.

Mr. C. E. R. Bruce (*communicated*): The main part of an atmospheric is radiated during the return stroke of a lightning flash, when a rapidly varying current flows in a rapidly lengthening conductor. Only when these two variations were combined was it possible to calculate at all accurately the field in the resulting atmospheric.* The velocity of the return stroke is given approximately by $v = v_0\epsilon^{-\gamma t}$, where $v_0 = 8 \times 10^9$ and $\gamma = 3 \times 10^4$, while the current is of the well-known double-exponential form $i = i_0(\epsilon^{-\alpha t} - \epsilon^{-\beta t})$. For an average wave, which reaches its maximum after about 5 microsec and falls to half value in about 25 microsec, $\alpha = 4{\cdot}4 \times 10^4$ and $\beta = 4{\cdot}6 \times 10^5$. The form of this wave was recently explained in terms of the charge distributed along the leader-stroke channel, the time required for its neutralization at any one level and the velocity of the return stroke.* Although, according to this theory, the current is not quite constant throughout the whole length of the return-stroke channel already formed, it was shown that this latter assumption introduces only a quite small error. If it is made, then the rate of change of electric moment during the return stroke is given by

$$\frac{dM}{dt} = 2i_t dt \int_0^{vt} v_t dt = 2\frac{i_0 v_0}{\gamma}(\epsilon^{-\alpha t} - \epsilon^{-\beta t})(1 - \epsilon^{-\gamma t})$$

The electric and magnetic fields at distance r in the atmospheric due to this rapid change in electric movement are given by

$$\mathscr{E} = \frac{M}{r^3} + \frac{1}{cr^2}\frac{dM}{dt} + \frac{1}{c^2 r}\frac{d^2M}{dt^2}$$

$$H = \frac{1}{cr^2}\frac{dM}{dt} + \frac{1}{c^2 r}\frac{d^2M}{dt^2}$$

in which $\mathscr{E}$ and M are in e.s.u., H is in e.m.u. and c is the velocity of light.

Fig. A shows the form of the resulting magnetic-field change

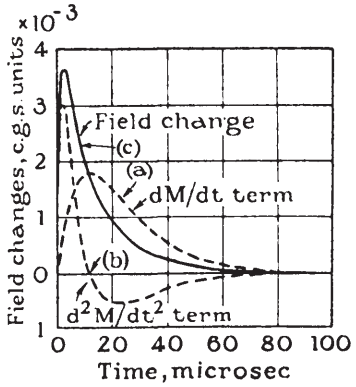

Fig. A.—Calculated magnetic- and radiation-field changes due to current in lightning channel.

to be expected at a distance of 3 km from an average flash, and Table A gives the crest values of the two components of the field at different distances, together with that of the resultant field. These will be seen to agree well with the values observed by Norinder† for strokes a few kilometres away, namely $0{\text{–}}5 \times 10^{-3}$ e.m.u. Good agreement is also obtained between the calculated values of the electric radiation field at different distances and those observed by Appleton and Chapman,‡ as shown in Table B.

As regards the "slow tail" observed in many atmospherics,

* Bruce, C. E. R., and Golde, R. H.: *Journal I.E.E.*, 1941, 88, Part II, p. 487.
† Norinder, H.: *Proceedings of the Physical Society*, 1937, 49, p. 364.
‡ Appleton, E. V., and Chapman, F. W.: *Proceedings of the Royal Society*, A, 1937, 158, p. 1.

Table A

VARIATION WITH DISTANCE OF MAGNETIC FIELD DUE TO LIGHTNING STROKES

Distance, km	3	4	5	6	8	10
	× 10 $^{-3}$	× 10^{-3}	× 10^{-3}	× 10^{-3}	× 10^{-3}	× 10^{-3}
Crest of dM/dt term, e.m.u.	1·75	0·98	0·63	0·44	0·25	0·16
Crest of d^2M/dt^2 term, e.m.u.	3·0	2·25	1·8	1·5	1·12	0·9
Crest of magnetic field, e.m.u.	2·6	2·55	2·0	1·75	1·2	0·95

Table B

VARIATION WITH DISTANCE OF RADIATION FIELD DUE TO LIGHTNING STROKE

Distance, km	50	100	175	350
$\mathscr{E}_r$ calculated, V/m ..	5·4	2·7	1·5	0·8
$\mathscr{E}_r$ observed, V/m	5·0	1·7	0·8	0·3

it has been shown* that it can be explained as the field radiated from the combined "a" and "c" portions of the electrostatic field change, using Appleton and Chapman's nomenclature, i.e. the field changes due to the leader stroke and the follow current after the return stroke proper.

The electrical-discharge theory of astrophysical phenomena† may have something to contribute towards the explanation of the origin of solar noise. I have elsewhere‡ summarized the evidence that the solar prominences are electrical discharges. That statement was prompted by the discovery of photographic evidence which appeared to indicate the existence of the mechanism of leader-return stroke in a discharge having its origin high above the sun's surface, analogous to the observations on lightning flashes from cloud to earth, and in the laboratory spark-discharge.

If the discharge theory does indeed afford the explanation of the outbursts of solar noise, then interesting conclusions follow. The observed radiation must be derived from the movements of individual electrons and depend on their mean free paths. As the discharge is propagated upwards into regions of lower pressure, the frequency of the emitted radiation will gradually decrease, as has been observed by Payne-Scott and others.§ However, somewhere there must appear the radiation due to the discharge as a whole, the "atmospheric," so to speak.

The change in the magnetic field due to such a discharge can be calculated, as were the field changes at great distances due to lightning flashes,‖ allowance being made in the calculation for both the rapid increase in length of the discharge channel and in the currents flowing therein to maintain the lateral corona currents from it. The calculation was made for a disturbance of the earth's field rising to 40γ in 15 min. The value obtained for the maximum current is 8×10^{13} amp, but as these discharges have diameters of the order of 10^3 — 10^4 km, this represents a current density of only 10^{-3} to 10^{-5} amp/cm^2. The electric field obtained at the assumed pressure of 10^{-6} atmosphere was 8×10^{-2} volt/cm, which is also quite a reasonable value, and the rate of energy liberation in the discharge is found to be 1/100 000 of the sun's total rate of energy liberation, which is again very reasonable.

As regards the general level of solar noise from the quiescent sun, I think the discharge theory may throw light on the observed phenomena. I have suggested* that sun and stars are surrounded by extensive tenuous atmospheres in which positive electric fields exist. The nature of the steady discharges resulting from this radial field depends on the current density and the gas pressure. Fig. B, due to Elenbaas,† shows schematically

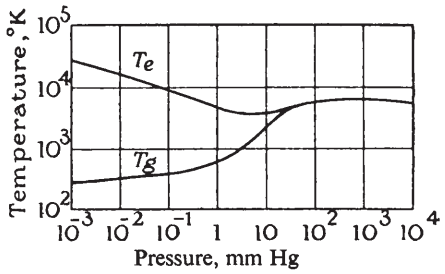

Fig. B.—Variation of electron temperature (T_e) and gas temperature (T_g) with pressure at constant current.

the variation of the temperature of the electrons and gas molecules in such discharges. Above about 10^{-2} atmosphere, these have the same temperature, the gas is thermally ionized and the opacity high; the conditions are those of the electric arc and the solar photosphere which on this view consists of a large number of transitory arcs in parallel. Above the critical gas pressure—about 10^{-2} atmosphere, as to which laboratory and solar observations agree—there is a region of low-pressure glow discharge, the chromosphere, in which the temperature of the electrons increases, while that of the gas molecules decreases with decrease of gas pressure, but the results of collisions between electrons and gas molecules are still in the visible region.

As the pressure falls still lower, the temperature of the electrons goes on increasing, and ultimately reaches values of the order of 10^6 degrees, required to account for the observed solar noise and the observed state of ionization of the atoms in the solar corona.

Major W. V. G. Fuge (*communicated*): My experience of the 600–3 000-metres band supports the existence of a local factor in radio noise.

In East Africa, good sites may be found within 30 miles of noisy ones. No circumstance, except possibly proximity to the end of a range of mountains, appeared to distinguish noisy sites, but altitude had an effect, and noise was worst in the wet season from November to April. Vegetation may have had some effect, but noisy sites were not found where it was thickest, and some of the worst sites were clear of it.

In East Africa on the top of a plateau about 1 000 ft high, radio noise started at 1100 hours local time, whereas at the foot, less than a mile away, it started at dusk, 1800 hours. At a site in the Black Sea area near high mountains, radio noise started at 1100 hours local time, while elsewhere in the area it started at dusk.

It is possible that radio noise may be transferred from one frequency to another by the mechanism of the Luxemburg effect.

The periods of 15 min just before dusk and after dawn in the tropics, when radio noise is increasing and decreasing respectively, and phenomenal ranges are workable, may be worth special study.

Mr. F. E. Lutkin (*communicated*): Some observations have been practicable in the past year or two at Singapore on the tropical storms from which many European atmospherics

* BRUCE, C. E. R.: *Nature*, 1941, 148, p. 165.
† BRUCE, C. E. R.: "A New Approach in Astrophysics and Cosmogony," London, 1944.
‡ BRUCE, C. E. R.: *Observatory*, 1946, 66, p. 263.
§ PAYNE-SCOTT, RUBY *et al*, *Nature*, 1947, 160, p. 256.
‖ BRUCE, C. E. R. and GOLDE, R. H.: *Journal I.E.E.*, 1941, 88, p. 487.
BRUCE, C. E. R.: *Proceedings of the Royal Society*, A, 1944, 183, p. 228.

* "A New Approach in Astrophysics and Cosmogony."
† ELENBAAS, W.: *De Ingenieur*, 1935, 50, p. 83.

emanate. Analysis of data obtained has not reached the stage where it can be quantitatively discussed, but a few salient points may be mentioned. To deduce his expected atmospheric level, Dr. Thomas used a standard lightning flash having the form of a vertical column to earth. Visual observations in Singapore show that not more than a few per cent of the lightning discharges occurring there are cloud-to-earth flashes. At least 95% are horizontal flashes between cloud layers, frequently visible as emanating in several directions from a cumulus head to a layer around it. Progression is sufficiently slow for the eye to follow; it occurs in steps and may take a second or more to complete. Flashes occur at heights of 10 000–15 000 ft, and, viewed from below, complex interwoven patterns are often seen. Vertical-gradient changes are often small, suggesting the neutralization of accumulations of opposite charge at comparable heights above the earth. Associated vertical-gradient changes may be positive or negative, up to twenty occurring with one flash, both signs being observed in one flash. The first two or three are often of one sign, while the remainder are of the opposite sign. It therefore seems that a comprehensive study of radiated waveforms and gradient changes in tropical regions must be undertaken before Dr. Thomas's forecast methods can be applied.

I agree with Dr. Booker that the relative positions of the intertropical front and the station whose noise factor is under consideration will probably be important in any periodic forecast requiring a knowledge of position of areas of thunderstorm activity. I would add that consideration should also be given to the effects of attenuation of atmospheric pulses in the highly-ionized regions of the atmosphere associated with the front, as these may impose preferential directions of propagation on them.

Mr. L. A. Moxon (*communicated*): As Dr. MacDonald states, the main defect of microwave crystal mixers is "lossiness" rather than noisiness. This is true for the majority of crystals, and in the absolute sense, but there are certain features of mixer-crystal noise to which I would like to draw attention. Typical mixer crystals are on the average perhaps 2 or 3 db down in performance compared with the best crystals; working with a low-noise i.f. amplifier, this difference in performance is due, on balance, more to excess noise than to additional loss.

With the best crystals, the noise in excess of the normal-room-temperature thermal noise level is extremely small, less than 1/10th of the thermal noise, but with some crystals it may be 3 or 4 times greater than the thermal noise. These extremes are typical of a fairly small percentage of crystals. So far as I know, no satisfactory theory of crystal noise has yet been put forward, and the enormous variation of excess crystal noise, which is of considerable practical importance, appears to represent a major unsolved problem.

In dealing with galactic noise, Mr. Hey and speakers in the discussion have been mainly concerned with the peaks of noise associated with the region of the galactic equator. If we turn our aerial beam so that it points away from this region towards one of minimum noise, we find that the noise level is still very considerable, as can be seen for example from the contour map obtained by Hey, Parsons and Phillips.* It is this minimum noise which is of chief interest to the engineer concerned with designing a receiver, since it determines the extent to which it is worth while reducing the noise factor. It is also to be noted that the really noisy portions of the galactic equator subtend a fairly small solid angle, so that, when receiving aerials are not both highly directive and pointed towards, say, Cygnus or Sagittarius, the total noise does not very greatly exceed the "minimum" level. This level is such that it roughly equals in power the internal noise level of the best existing receivers at 90 Mc/s; it is about 15 times greater at 40 Mc/s.

There is so far no proof that this noise is of galactic origin, and I suggest that, strictly speaking, the term "galactic" should be applied for the present only to the increments of noise level associated with particular directions in space. In this connection it would be interesting to know whether the contours obtained by Hey, Parsons and Phillips for directions well removed from the galactic equator are repeatable throughout the year.

As I have indicated previously,† the available evidence tends to suggest that the minimum noise level and the increments associated with the galactic equator vary in a somewhat different manner with frequency. This does not necessarily imply a difference of nature, since some attenuation factor may be operative, and it would be interesting to know whether any reliable information is available on the subject of attenuation of radio waves in the galaxy. In this connection it has been suggested that the total galactic attenuation is negligible for the directions of minimum depth; in this case the equivalent noise temperature associated with the radiation resistance of an aerial pointed in those directions, being the average effective noise temperature of all those particles of matter capable of absorbing radiation from the aerial, should be typical of intergalactic space or of remoter galaxies. It would be interesting to know Mr. Hey's views on whether this point merits further attention.

* *Proceedings of the Royal Society*, A, 1948, **192**, p. 425.

† MOXON, L. A.: "The Variation of Cosmic Radiation with Frequency," *Nature*, 1946, **158**, p. 758.

THE AUTHORS' REPLIES TO THE ABOVE DISCUSSION

Dr. D. K. C. MacDonald (*in reply*): In reply to Mr. Bell, I should like to protest strongly against the suggestion that Nyquist "led us off on the wrong track by using thermodynamics quite regardless of the question of internal mechanism." Where it is quite evident that a state of true thermal equilibrium obtains—as in the case of Johnson noise in a passive resistor—the appropriate and most direct approach is surely to use the general principles of thermodynamics, as Nyquist in fact did. Later alternative demonstrations of Nyquist's theorem based on a consideration of the detailed mechanism of conduction only serve to show the tenability of the mechanism and/or statistics adopted for this particular problem. Where, on the other hand, it is not clear that thermal equilibrium exists, as in the general case of the thermionic valve receiving energy from an external battery, we are forced to a detailed examination of the processes involved, as was undertaken by North and Schottky. I agree with Mr. Bell, however, that it is somewhat unfortunate that experiments on diodes, apparently the simplest structures, yield rather conflicting results. It appears very desirable that this situation should be clarified experimentally, since it seems to some extent unsatisfactory to tackle the high-frequency space-charge problem if any appreciable discrepancies remain at low frequencies. It is understood that work is in progress at Cambridge in this connection.

Dr. T. W. Wormell and **Mr. E. T. Pierce** (*in reply*): In reply to Mr. Whelpton, the observations described by us give no information on the effects of atmospherics at frequencies above about 30 kc/s. We agree that the range of frequencies immediately above this is of great importance from the practical point of view.

Mr. Lutkin's description of storms at Singapore is interesting. The proportion of flashes to earth is, of course, much greater in the storms of this country, but many of the phenomena he describes are not infrequently observed here. In particular, the

visible discharge path may be far from vertical, the associated change in vertical gradient may be very complex,* involving changes of both signs, and the deviation of the luminosity may be quite perceptible to the eye and sometimes persist for more than a second.

Dr. H. A. Thomas (*in reply*): I am indebted to Dr. Booker for the suggestion that the equatorial front may have a prominent effect on the noise level at tropical locations. It will obviously be necessary to make a very careful analysis of existing data before such correlation can be satisfactorily established, and it is proposed to follow this line of investigation as soon as possible.

The determination of noise level on frequencies below 300 kc/s is undoubtedly a matter of great importance. Equipment has been designed for making measurements at a considerable number of locations, and such equipment will shortly be available. Reliable data should be available in about two or three years' time.

In reply to Mr. Ross, the noise level at Delhi does appear to be unexpectedly low; with the present sensitivity of the measuring equipment it is not possible to obtain a true picture of the diurnal variation, but, when improved equipment of much higher sensitivity now under construction is installed, it will be possible not only to obtain this characteristic but also to check the present figures.

In the Appendix referred to by Mr. Millington, the permissible field intensity is based on an interference ratio and neglects noise of all forms. It is admitted in Section 3 that for the lower frequencies in the 3–30 Mc/s band atmospheric noise may often be greater than 0·3 microvolt per metre, and the protection of this minimum field will then be greater than necessary. In such cases the protection ratio given for different types of service should be applied to the median noise field.

I am grateful to Mr. Johnson, Mr. Caradoc Williams and Major Fuge for the information they give confirming the view that large differences in noise level may occur over relatively small distances. It will be a long time before sufficient measuring equipment can be installed at sufficient locations to obtain scientific proof of these views; in the meantime, any relevant information obtained by operational personnel would be of considerable value.

Mr. J. S. Hey (*in reply*): Replying to Mr. Moxon, many writers are now using the term "galactic noise" in preference to "cosmic noise," not simply because the higher-level regions of power flux correspond to galactic structure, but also to avoid any possible confusion with the term "cosmic rays." I agree that so far no proof has been given that the low-level regions are necessarily of galactic origin. In these regions the distribution is more difficult to determine than it is near the galactic equator, and we cannot rule out the possibility of some variations. I agree that further investigations at various frequencies are desirable.

Mr. M. Ryle (*in reply*): Mr. Millington has referred to the suggestion made by Menzel and Salisbury* that the sun emits radiation of very low frequency. It seems possible that oscillations of a few cycles per second might originate in regions of the corona containing space-charges, by a mechanism similar to the plasma oscillations observed in gas-discharge tubes. The intensity of the radiation emitted by such processes could be deduced from a knowledge of the maximum potential available in the sun and the radiating efficiency of the discharge system. It is possible to make a very rough estimate of the available potential from the maximum electron temperatures which are deduced from measurements of the radio noise at high frequencies. Such estimates suggest intensities at the earth which are considerably smaller than those required by Menzel and Salisbury to account for the various terrestrial phenomena (0·01–1·0 volt/cm).

In a recent communication, Willis† described experiments on the fluctuations of the horizontal component of the earth's magnetic field at a site situated far from possible sources of man-made disturbance. The measurements covered the frequency range 5–1 000 c/s, and the results obtained corresponded to intensities very much smaller than those initially observed by Menzel and Salisbury (of the order of 20 μV/cm for a band of 25–400 c/s).

A final conclusion must await further experiments by Menzel and Salisbury.

* WORMELL, T. W.: *Philosophical Transactions of the Royal Society*, A, 1939, **238**, p. 287.

* *Nature*, 1948, **161** p. 91.

† *Ibid.* 1948, **161**, p. 887.